

Elements of Tiny Plasma Spectrometers

Completed Technology Project (2015 - 2017)



Project Introduction

We propose to advance major elements of a miniaturized plasma spectrometer for flight on future missions. This type of instrument has been developed and successfully flown before. In these cases the sensor was tiny but the supporting electronics were macroscopic (5kg, 5W) in terms of their physical resource requirements. There are both scientific and engineering motivations to develop tiny plasma spectrometer systems. This IRAD is focused on targeted miniature plasma spectrometer system element invention, development and TRL advancement.

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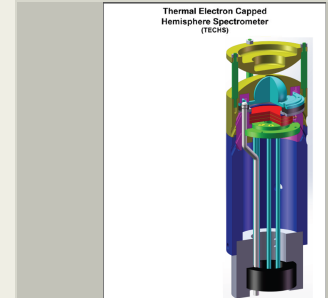
Internal Research & Development (IRAD)

Introduction and Objectives

The need for electrostatic analyzers to measure ion and electron fluxes in near-Earth space is nearly ubiquitous in Heliophysics missions. In the latest example NASA's MMS mission, launched in March 2015, features fully 32 electron and 32 ion spectrometers. These plasma measurements are central to the vast majority of such missions. The ranges of fluxes and energies to be covered are extremely wide, in view of the wide variety of plasma conditions across the heliophysics realm. The GSFC Heliophysics Division enjoys a distinguished tradition of developing and flying these devices and is well placed to provide future leadership in this area.

Extremely low physical resource instruments, suitable for example for flight on CubeSats, are in high and growing demand. Such minimal resource payloads may well comprise the elements of future constellations providing networks of observation points, as called for in both the current and past HPD roadmaps. Small constellations of larger spacecraft have been flown. NASA's Themis & MMS and ESA's Cluster are examples. Current small bus concepts require scientific instruments with phenomenally small physical resource requirements. Further, the kinetic electron distributions below 10 eV in Earth's ionosphere are almost completely unexplored. Electron spectrometers in this energy range will only work if they are tiny, owing to the small scale gyro-motion of these low energy particles in the strong geomagnetic field at low altitudes. Yet these low energy electron kinetics are likely critical to both ionospheric plasma processes and chemistry. **The time to focus on resource minimization for workhorse plasma instruments is now!**

The overarching goal of this IRAD is to advance the TRL for elements of highly miniaturized top hat electrostatic analyzers to be built at Goddard for future missions, by designing, building and testing prototypes. The design elements targeted, all in miniature, are 1) the HVPS, 2) 1D microchannel plate 1D imaging, 4) a command and data handling (C&DH) card, 4) the instrument system, 5) extension of ESA energy range via enhanced tolerance of large electric fields and 6) accommodation on either a CubeSat or deployed from a



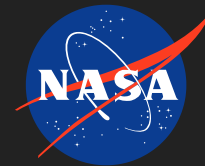
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larger spacecraft. We have detailed mechanical designs for an extremely small electrostatic analyzer, the Thermal Electron Capped Hemisphere Spectrometer (TECHS) [Pollock et al., 1996, 1998; Adrian, 2000]. This was developed, along with a relatively large and heavy electronics suite, for flight on the SCIFER sounding rocket in 1994 and the Japanese SS520-2 sounding rocket in 2002, with an attempt at a new (resistive) imaging system. The SCIFER flight was successful. On the Japanese rocket flight, the energy measurements worked well but no useful angular information was obtained. Therefore, we face several challenges in order to offer viable instrument concepts in this class for future missions. These challenges form the basis of the objectives listed below, which build on a previous IRAD (Pollock et al., FY2013). Though we list objectives associated with a multi-year program of IRAD (or HTIDES) development, here we only address the first year objectives in this proposal:

Year 1:

- 1) Demonstrate, in a CubeSat form factor, a prototype multi-output HVPS with switchable MCP bias for ions or electrons and with a stepper range from 0.15 to 1500 V (possibly to be extended in future to 4kV at top end.
- 2) Demonstrate functionality of already built highly miniaturized prototype delay line anode.
- 3) Accommodate delay line anode into the highly miniaturized ESA;
- 4) Develop design concept for a system, including: 1) HVPS, 2) LVPS, 3) signal processing and 4) control, data processing, & spacecraft interfaces, all in CubeSat form factor.

Rationale & Business Justification

The GSFC Heliophysics Division enjoys a distinguished tradition of developing and flying plasma analyzers and is well positioned & suited to provide future leadership in this area. This research will contribute directly to the maturation and competition of several specific future candidate missions (DIONE, MEMEX, Aether, sounding rockets) and to the enhancement of our ability to win future missions and instrument roles where physical resources are scarce. Progress on this IRAD can be cited in our responses to ROSES and Explorer opportunities in 2016 and beyond. We have been engaged in the past in a sounding rocket collaboration with our Japanese colleagues at ISAS, under the leadership of Dr. Y. Saito. The attached letter invites us to fly the TECHS instrument on their SS520-3 in December 2016. We will be **unable to participate** owing to the **lack of readiness** of this instrument. This demonstrates that there is **unmet demand** for this scientific capability, independent of the low physical resource characteristics that is our focus with

Organizational Responsibility

Responsible Mission Directorate:

Mission Support Directorate (MSD)

Lead Center / Facility:

Goddard Space Flight Center (GSFC)

Responsible Program:

Center Independent Research & Development: GSFC IRAD

Project Management

Program Manager:

Peter M Hughes

Project Manager:

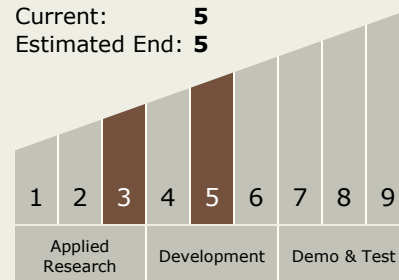
Nikolaos Paschalidis

Principal Investigators:

Mark L Adrian
Thomas E Moore

Technology Maturity (TRL)

Start: **3**
Current: **5**
Estimated End: **5**



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this IRAD.

Plan of Research & Development

We have in hand detailed designs for all elements of the previously flown TECHS system, including the electrostatic analyzer, MCP assembly, boom and hinge assembly, and the heavy & large EBOX assembly. We also possess a built TECHS ESA and all necessary MCPs and test chambers/sources for this development. A preliminary HV card design in the required form factor exists (IRAD 2013, work of Julian Ramirez & Eric Young / 563). There are three areas of new development for this first year. These are, the function and accommodation of the Delay Line Anode and signal processing electronics, design & function of a versatile HVPS in CubeSat-compatible form factor, building from Eric Young's preliminary design, and concept development of required system elements and their accommodation in cube-sat form factors.

We will utilize human resources from both Goddard's civil service and contractor work force. In addition, we will utilize the services of two graduate students and at least one post-doc, all of whom are independently funded. The delay line anode has been designed and fabricated in collaboration with Dr. Mark Adrian as part of an earlier IRAD project. Vacuum testing of this prototype is ready to move forward. Previous simulation and bench testing of this device gives us reasonable confidence that the prototype will work as expected. There is a de-scope option available here. The current prototype is a 32-pixel system. If necessary, we can back off to a 16-pixel system, providing added margin in the layout and function of the device, while retaining acceptable scientific performance for most purposes.

It is always the case with these highly miniaturized top hat ESAs that mechanical accommodation of features, particularly high voltage and other electrically sensitive features, requires extremely innovative electro-mechanical design. Once our anode system is verified to function satisfactorily, we will move to the fabrication of an accommodatable prototype for mating with the small MCP detector. This is expected to be one of the more challenging developmental efforts.

The design of an electronics system to support our small ESAs is centered around the C&DH card. This card will provide all ESA sensor control functions, receive and organize data received from the sensor's delay line position sensing system and provide all analogue and digital electrical interfaces to both the sensor and a host bus. We have two candidate C&DH card concepts. The first has its heritage in the MMS/FPI/DES C&DH card originally designed at GSFC. This card has been re-designed to fit into a CubeSat package and to provide the flexibility (based on FPGA programming) to service a range of plasma like sensor architectures. The second has been developed in Code 564

Technology Areas

Primary:

- TX14 Thermal Management Systems
 - └ TX14.3 Thermal Protection Components and Systems
 - └ TX14.3.2 Thermal Protection Systems

Target Destination

Earth

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as a flexible modular C&DH for low resource flight instruments. We will perform a trade of these two candidates and select one to serve as the basis for a preliminary system level electronics and packaging design

The performance and resource targets associated with the resulting instrument are shown in Table 1. It is notable in the past, the TECHS upper energy has been only 100 eV/q. This is suitable for ionosphere-focused experiments. However we will want to extend this to the highest energies possible for orbital CubeSat applications, as discussed briefly below.

Electron ESA**System****Units****E/q (e) Range**

0.3 – 10,000

Na

eV/q

Energy Resolution ($\Delta E/E$)

0.08

Na

-

Angular FOV

6 x 360

Na

Deg

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Angular Resolution

6 x 11.25

Na

deg

Pixel Sensitivity

1×10^{-5}

Na

$\text{cm}^2\text{-sr-eV/eV}$

Mass

0.5

3

Kg

Power

0.5

3

W

2D (energy/angle) time resolution

1

1

S

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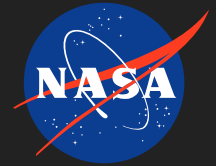


Table 1: TECHS Design, Performance, and Resource Parameters.

Future Development

In addition to the first year objectives listed above, there are several additional development steps that we would like to take with this instrument in the. These include:

Develop and test a prototype C&DH card.

- 1) Perform detailed design and build a prototype of a suitable C&DH card.
- 2) Build and perform beam testing of a prototype of the entire system;
- 3) Optimize ESA geometry and materials to stand off maximum voltages to maximize upper energy range with use of highly miniaturized ESA.
- 4) Design distinct approaches such that the miniaturized ESA can either mounted in a small enclosure (CubeSat bus), proximate to its electronics or on a deployable boom.
- 5) Extend the upper energy range of the ESA to allow plasmas up to 10-20 keV/q to be sampled. This will involve changing our current 0-5 V sweep supply to one that covers more like 0-2 kV and also testing our ESA to determine how high a voltage we can apply safely.

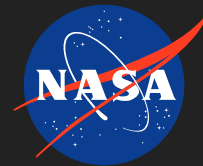
Budget

Budget details for this one year effort are provided in Table IRAD Step-2 template. No specialized technical or test equipment are needed. No travel is required. Engineering support will include mentoring of graduate students and a post-doc who are all independently funded and who will carry out much of the instrument assembly and testing..

In all aspects of this IRAD, we will be leveraging previous work in order to produce and demonstrate major leap forward. Major elements of this system are designed and simply require modification and introduction of targeted innovation in order to provide a complete set of system elements that are proven and ready for implementation. The miniature MCP supply has already received preliminary design. The C&DH candidates are mature and have both flown in other instruments. The delay line anode for the TECHS form factor has been designed & simulated. A prototype has been fabricated and bench tested and awaits vacuum testing with an assembled MCP stack. In each case, we will apply the engineering services required for completing these developments, utilizing the expertise of the same engineers that have brought us to this point in development whenever possible.

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The program will be fully managed in Code 673. Dr. Craig Pollock (10%) will provide overall leadership. Dr. Mark Adrian (30%) will provide technical leadership and will provide hands-on participation in all elements of this IRAD. Dr. Marilia Samara (10%) will perform all scheduling, procurement, and financial management functions. Drs. Pollock, Adrian and Samara will actively mentor more junior scientific and engineering team members.

Procurement

Civil Servant Time (FTE)

Intern Request

We would like to support a summer intern, who is a rising senior in electrical engineering. This person will help with either the HVPS fabrication, test, & test report or the definition of the system level implementation.

References:

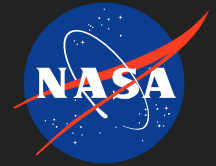
Adrian, M.L., Rocket Measurements of the thermal and superthermal electron distributions in the prenoon topside auroral ionosphere and ionospheric cleft, 2000.

Pollock, C.J. et al., Fast Plasma Investigation for Magnetospheric Multiscale, Submitted to Space Science Reviews, May 2015.

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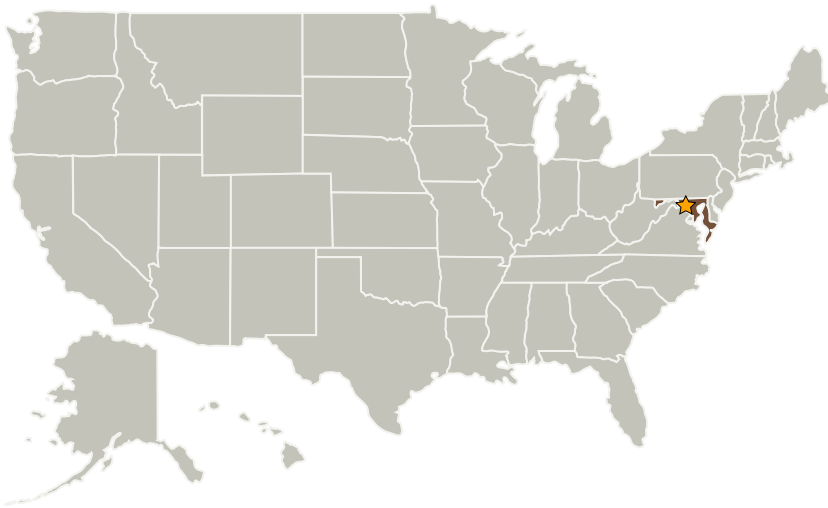
D.T. Young, 1998.

Pollock, C.J., T.E. Moore, M.L. Adrian, P.M. Kintner, and R.L. Arnoldy, SCIFER – Cleft region thermal electron distribution functions, *Geophys. Res. Lett.*, **23** (14), 1881, 1996.

Anticipated Benefits

MEME-X Explorer.

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
★ Goddard Space Flight Center (GSFC)	Lead Organization	NASA Center	Greenbelt, Maryland

Primary U.S. Work Locations

Maryland

Project Transitions



October 2015: Project Start

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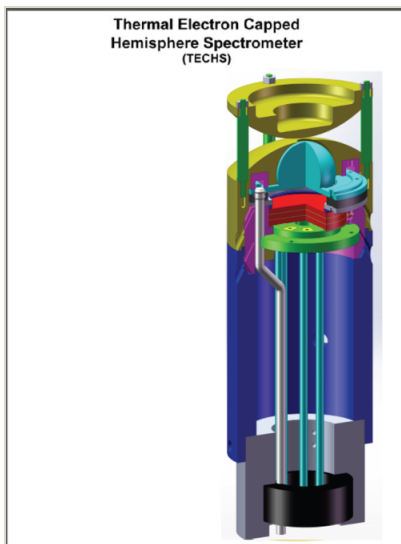


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✓ **September 2017:** Closed out

Closeout Summary: The purpose of the Goddard Space Flight Center's Internal Research and Development (IRAD) program is to support new technology development and to address scientific challenges. Each year, Principal Investigators (PIs) submit IRAD proposals and compete for funding for their development projects. Goddard's IRAD program supports eight Lines of Business: Astrophysics; Communications and Navigation; Cross-Cutting Technology and Capabilities; Earth Science; Heliophysics; Planetary Science; Science Small Satellites Technology; and Suborbital Platforms and Range Services. Task progress is evaluated twice a year at the Mid-term IRAD review and the end of the year. When the funding period has ended, the PIs compete again for IRAD funding or seek new sources of development and research funding or agree to external partnerships and collaborations. In some cases, when the development work has reached the appropriate Technology Readiness Level (TRL) level, the product is integrated into an actual NASA mission or used to support other government agencies. The technology may also be licensed out to the industry. The completion of a project does not necessarily indicate that the development work has stopped. The work could potentially continue in the future as a follow-on IRAD; or used in collaboration or partnership with Academia, Industry and other Government Agencies. If you are interested in partnering with NASA, see the TechPort Partnerships documentation available on the TechPort Help tab. <http://techport.nasa.gov/help>

Images



Tiny Plasma Spectrometers

Tiny Plasma Spectrometers
(<https://techport.nasa.gov/image/20801>)

Project Website:

<http://sciences.gsfc.nasa.gov/sed/>